Di-boson Physics @ Tevatron

(focus on results since ICHEP 2006)

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- Di-bosons as a step towards Higgs & other new physics
- Common Experimental Challenges
- Recent Results
  - Wγ, Zγ
  - WZ
  - ZZ (3 new results for Moriond)

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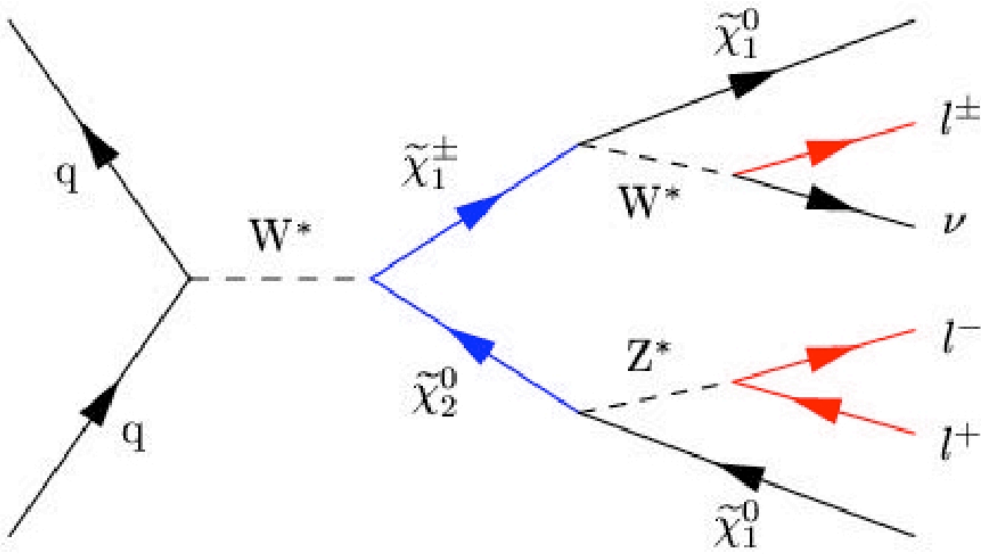
Finding Rare Processes

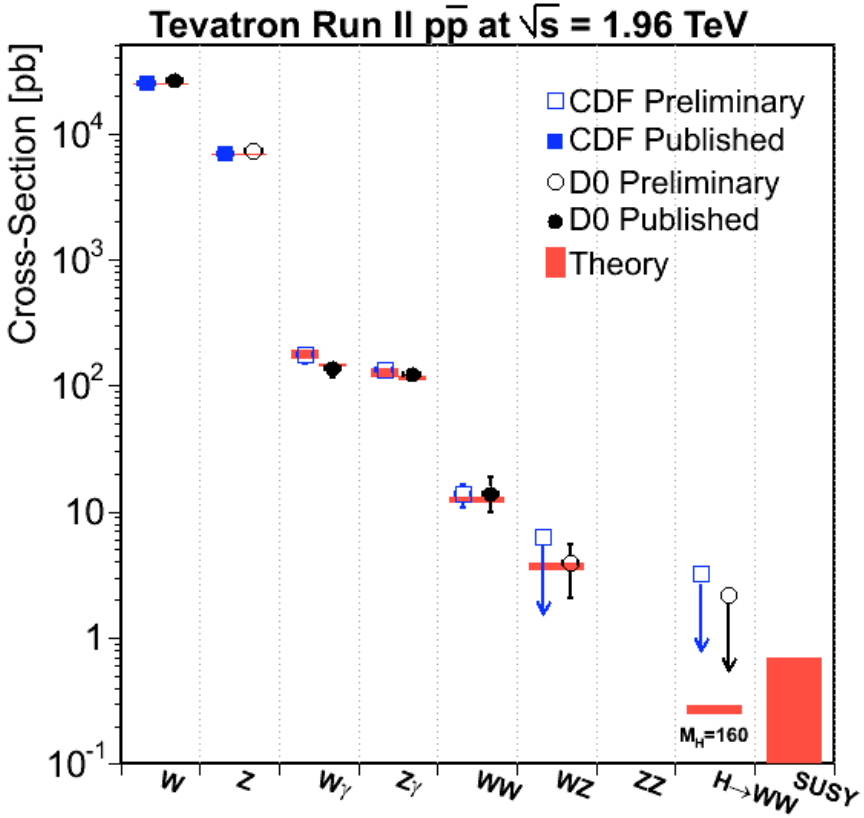
- Di-bosons are *reality check* on path to finding *multilepton final states* with *very small σ x Br* (e.g. Higgs, SUSY, …).
- Todays 1st observation is tomorrows background (e.g. WW for Higgs, WZ for SUSY, …).

• 3 lepton + MET common to: WZ, SUSY, …

• 2 lepton + MET common to: WW, ZZ, Higgs, …



Status as of ICHEP 2006

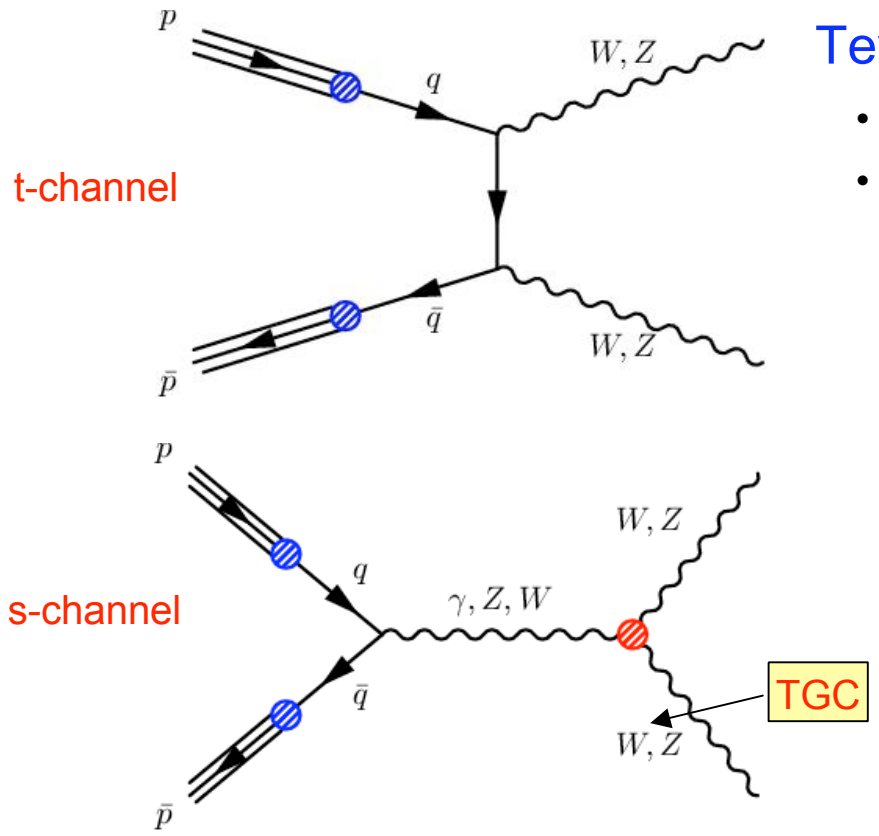


Measuring Triple Gauge Couplings

Boson pair production probes gauge boson self-interactions

⇒ consequence of non-Albelian nature of $SU(2)_L \otimes U(1)_Y$

⇒ sensitive to new physics in trilinear gauge couplings (TGC)



Tevatron ($\bar{p}p$) complementary to LEP (e^+e^-)

- Sensitive to different TGC combinations
- Tevatron explores higher $\hat{s}$ than LEP

$$
\begin{aligned}
q\bar{q}' &\to W^{(*)} \to W\gamma : WW\gamma \\
q\bar{q}' &\to W^{(*)} \to WZ : WWZ \\
q\bar{q} &\to Z/\gamma^{(*)} \to WW : WW\gamma, WWZ \\
q\bar{q} &\to Z/\gamma^{(*)} \to Z\gamma : ZZ\gamma, Z\gamma\gamma \\
q\bar{q} &\to Z/\gamma^{(*)} \to ZZ : ZZ\gamma, ZZZ
\end{aligned}
$$

Absent in SM

Common Experimental Challenges for WW, WZ, ZZ, Wγ, Zγ

- Require trigger e or μ with pt>20GeV
- Allow 2nd,3rd,4th lepton to be pt>10GeV.
  - and lepton and/or Z vetos to reduce feeddown
- γ with pt >7GeV
- Isolation cut(s) to reduce fakes from jets
  - Calorimeter isolation
  - Track isolation
- MET cut for WW/Z/γ, ZZ->ll$\nu\nu$ but not ZZ->4l and Zγ
  - fake MET due to mismeasured j,e,mu or E_T fluctuations
- **Measure acceptance corrections & fake rates in data.**

$Z\gamma$, $W\gamma$

- New at DPF 2006:
  - CDF: $Z\gamma$, $W\gamma$
  - D0: $W\gamma$ radiation amplitude zero
- New at ICHEP 2006:
  - D0: $Z\gamma$

$Z\gamma$ in $ee\gamma$

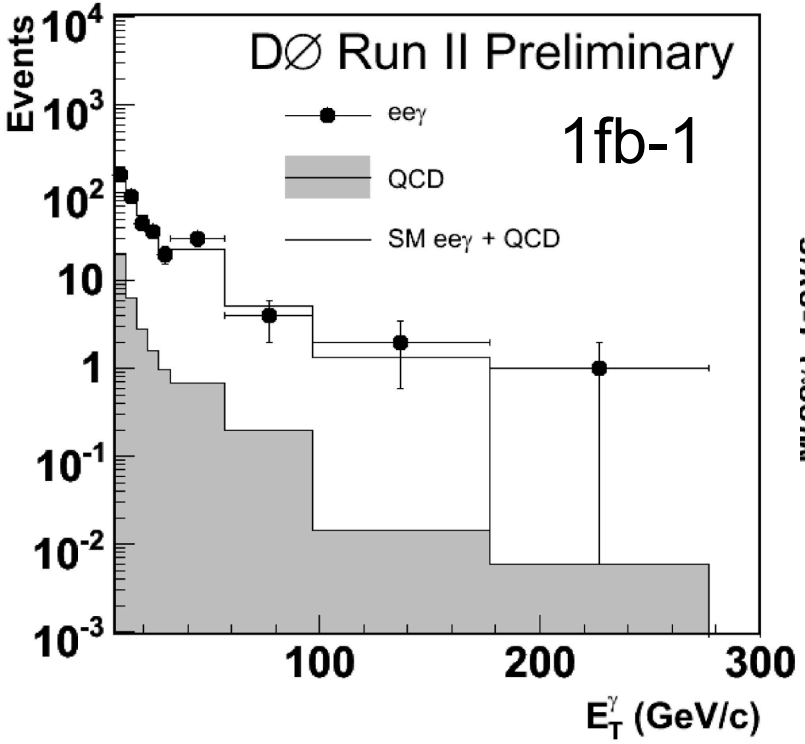
Large clean samples, consistent with SM. (~400 events out of which 30-50 are bkg)

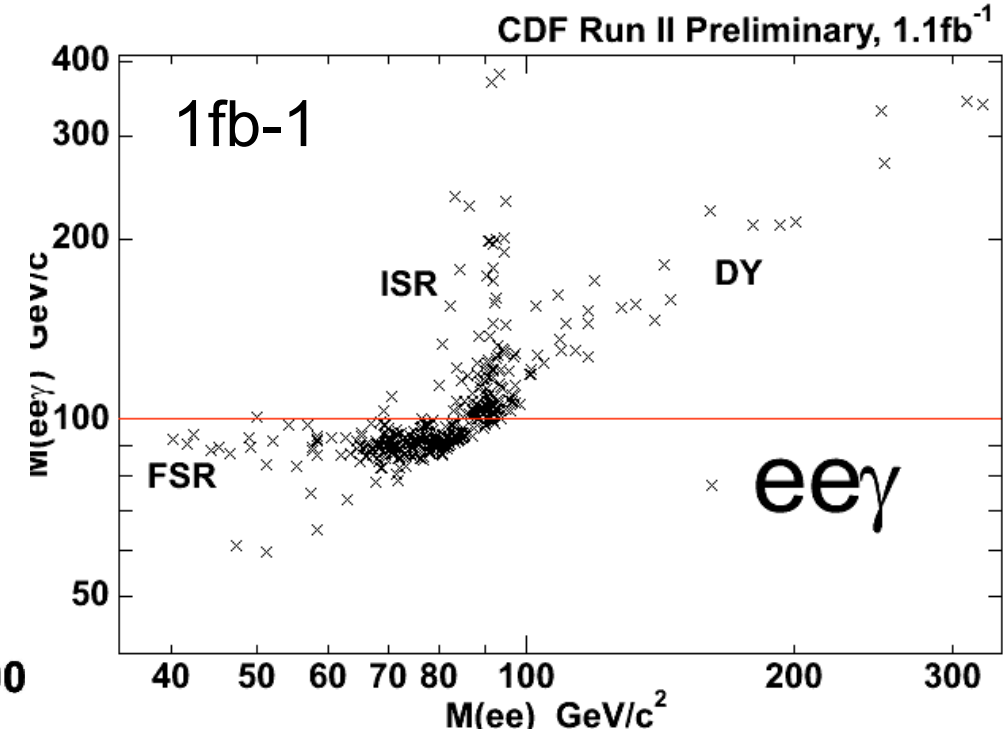
Cross Section times Branching Fraction:

CDF: $4.9 \pm 0.3 \pm 0.3(syst) \pm 0.3(lumi)\, pb$

D0: $4.51 \pm 0.37 \pm 0.27(lumi)\, pb$

Theory: $4.7 \pm 0.4\, pb$



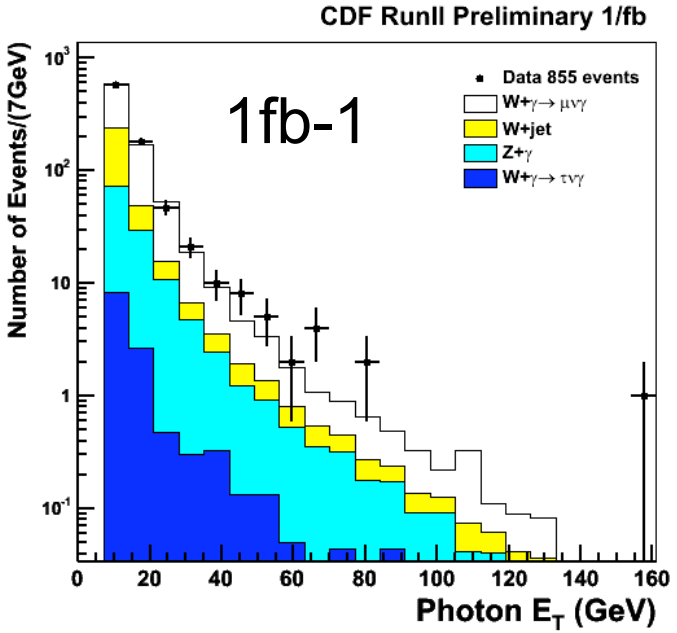


Wγ

D0: σ x BR above 90GeV in 3-body transverse mass to reduce FSR.

CDF: total σ x BR.

Both in agreement with SM.



CDF: $19.11 \pm 1.04 \pm 2.40 \pm 1.11 pb$

SM: 19.3 ± 1.4

D0 e: $3.12 \pm 0.49 \pm 0.19 pb$

D0 μ: $3.21 \pm 0.49 \pm 0.20 pb$

SM: $3.21 \pm 0.08 pb$

μγ only

$W\gamma$	541.7±4.02(stat.)±1.57(sys.)
W+jet	194.3±0.15(stat.)±66.91(sys.)
$Z\gamma$	112.0±0.39(stat.)±0.32(sys.)
$W\gamma(\tau)$	12.4±0.60(stat.)±0.04(sys.)
Number of Total	860.4±29.25(stat.)±66.95(sys.)
Number of Observed	855

0.9fb-1

	Muon Channel	Electron Channel
Luminosity	878 pb^{-1}	933 pb^{-1}
W + jet Background Events	98 ± 12 (stat. + sys.)	148 ± 17 (stat. + sys.)
ℓeX Background Events	6 ± 2 (stat. + sys.)	34 ± 4 (stat. + sys.)
$W\gamma \to \tau\nu\gamma$ Background Events	2.6 ± 0.4 (stat. + sys.)	1.7 ± 0.2 (stat. + sys.)
$Z\gamma \to \ell\ell\gamma$ Background Events	8 ± 1 (stat. + sys.)	-
Candidate Events	245	389
Expected Signal	130 ± 9	211 ± 14
Measured Signal	130 ± 18	205 ± 26

Radiation Amplitude Zero in Wγ

SM at LO has amplitude zero in COM production angle.

$$u\bar{d} \rightarrow W^{+}\gamma, zero\ at\ \cos\theta_{CM} = -1/3$$

$$d\bar{u} \rightarrow W^{-}\gamma, zero\ at\ \cos\theta_{CM} = +1/3$$

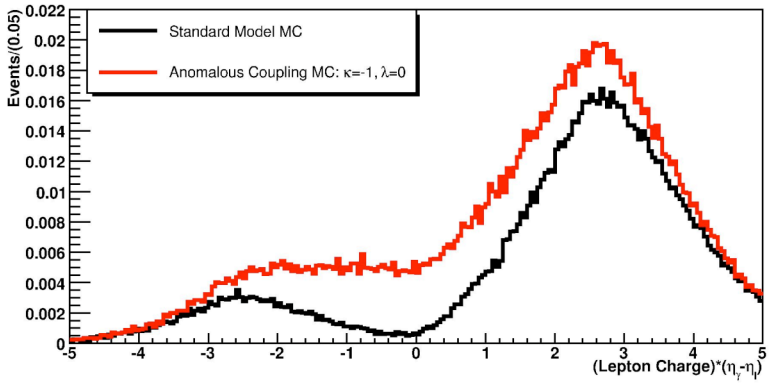
Experimentally visible as dip in γ-lepton charge-sign rapidity difference.

Data in agreement with expectations.

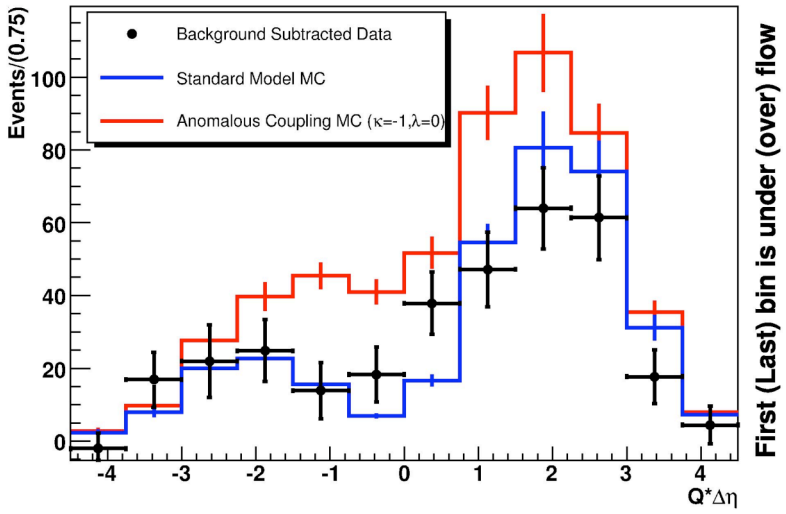
Provides information to limit aTGC, that is orthogonal to cross section.

3-body transverse mass cut to enhance prompt production,

Generator Level MC



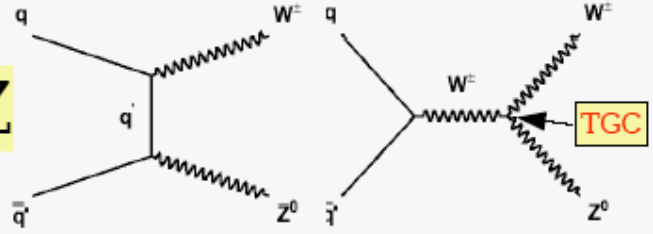
Bkg subtracted data



Status in WZ, ZZ as of ICHEP 2006

Involves a single SM triple gauge coupling:

WZ

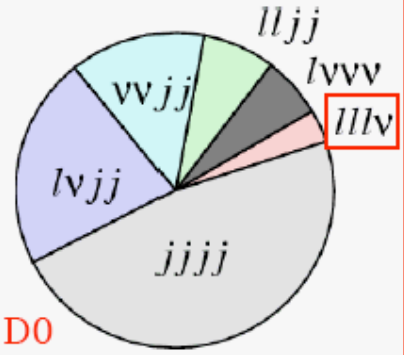


- Not available @ LEP
- Measure WWZ coupling independent of WWγ
- Yet to be observed (>5σ)

First evidence (3.3σ) from D0

NLO cross section: 3.7 ± 0.1 pb

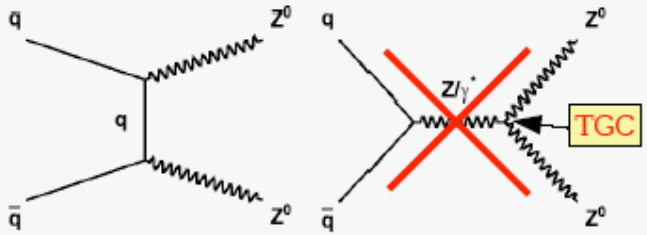
Campbell,Ellis, Phys.Rev. D60 (1999) 113006



BR(WZ → 3 e,μ) = 1.8%

Triple neutral gauge couplings absent in SM:

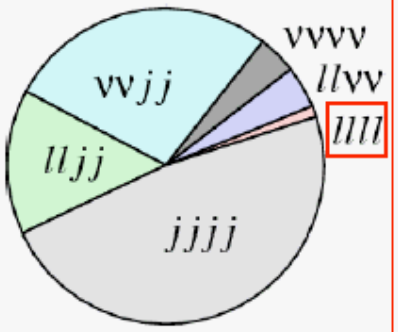
ZZ



- Search for ZZγ or ZZZ coupling (=0 in SM)
- SM ZZ production not yet observed at hadron collider

NLO cross section: 1.4 ± 0.1 pb

Campbell,Ellis, Phys.Rev. D60 (1999) 113006



BR(ZZ → 4 e,μ) = 0.5%

- **Use the purely leptonic final state for SM observation.**
- **Use the lνjj and lljj final state for new physics searches.**
- **Ignore the jjjj final states because of too much bkg.**

News Since ICHEP 2006

- WZ in lllν by CDF @ DPF
- Search in ZZ -> llll by CDF @ DPF

- Search in ZZ -> llll by D0 @ M.EWK
- More data in ZZ -> llll by CDF @ M.QCD
- Search in ZZ -> ll$\nu\nu$ by CDF @ M.QCD

Maximizing Lepton Acceptance

9 lepton categories, 4 trigger lines

Electrons

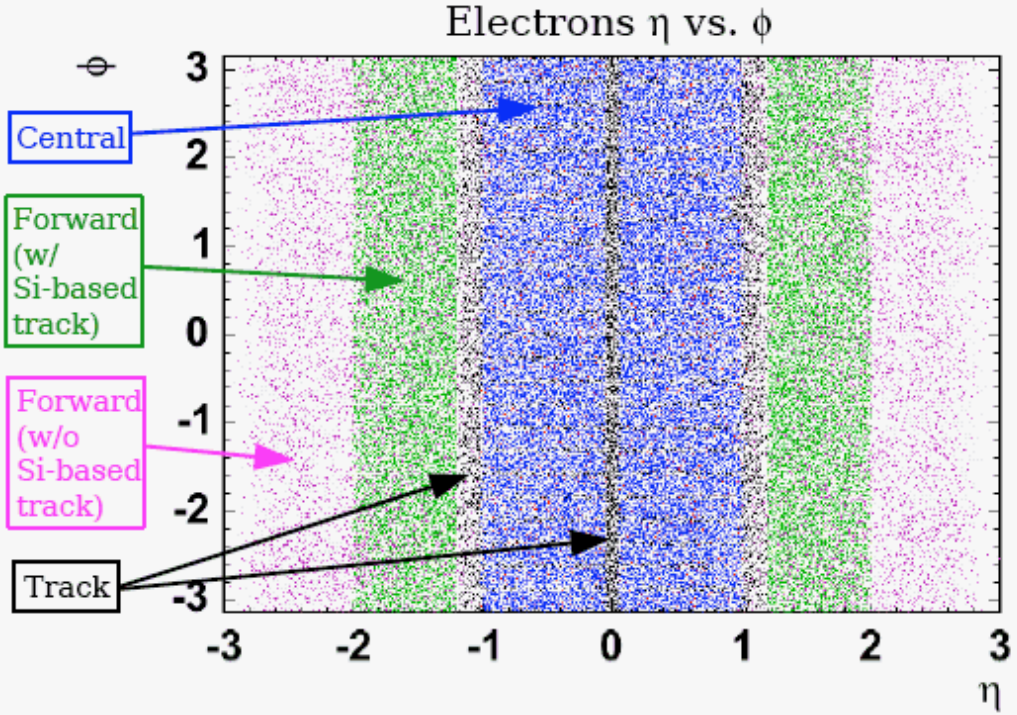
- Central calorimeter fiducial
- Forward calorimeter fiducial
  - With or w/o Si-based track

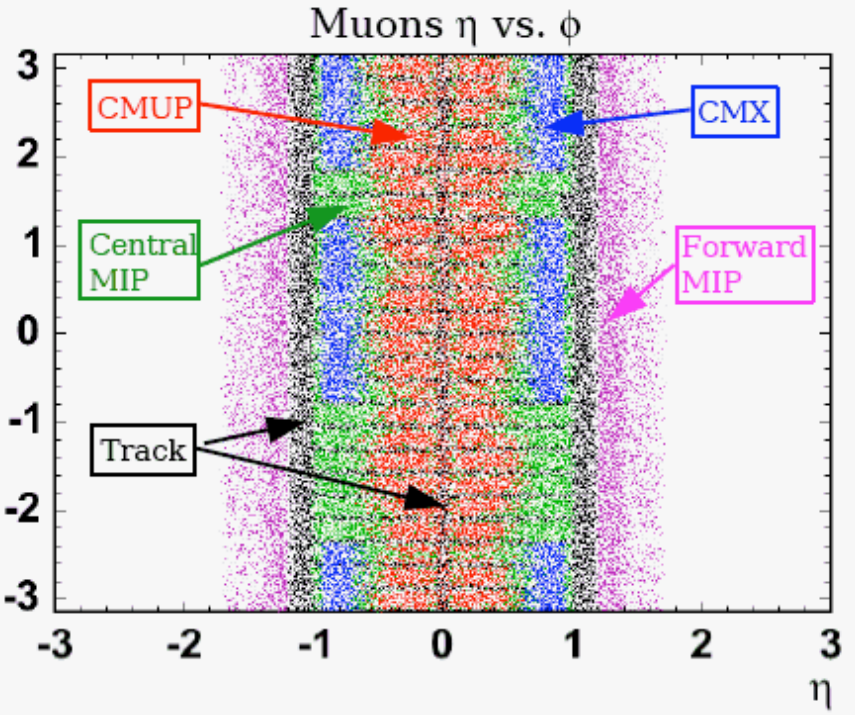
Muons

- CMU+CMP (CMUP) stubs
- CMX stub
- Minimum Ionizing Particle (MIP)
  - central and forward region

Track-only leptons

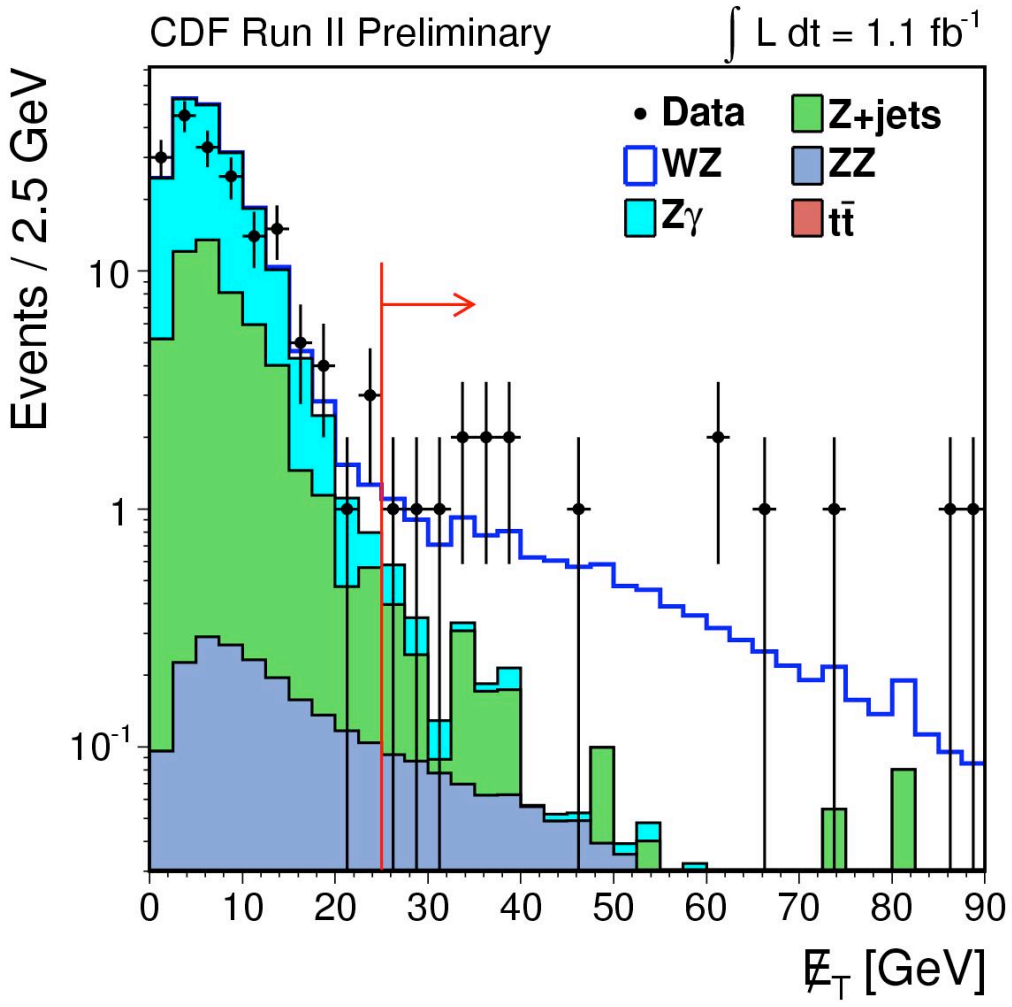
- Fill in regions not fiducial to a calorimeter (shower max)
- Considered flavor neutral (e or μ)





First Observation of WZ

$$5.0^{+1.8}_{-1.6}\ pb\ (stat + syst)$$



16 evts in lllν signal region.
2.7+-0.4 expected bkg.

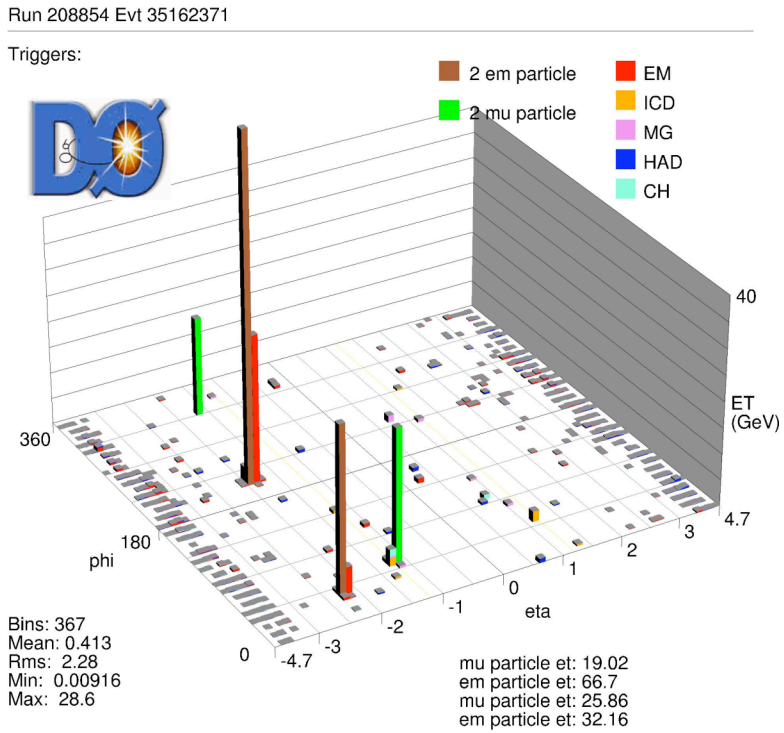
Statistical Significance 6σ
(based on yield and MET)

Theory: 3.7+-0.3pb @ NLO
(Campbell & Ellis)

Source	Expectation ± Stat ± Syst ± Lumi
Z+jets	1.22 ± 0.27 ± 0.28 ± -
ZZ	0.89 ± 0.01 ± 0.09 ± 0.05
$Z\gamma$	0.48 ± 0.06 ± 0.15 ± 0.03
$t\bar{t}$	0.12 ± 0.01 ± 0.01 ± 0.01
WZ	9.79 ± 0.03 ± 0.31 ± 0.59
Total Background	2.70 ± 0.28 ± 0.33 ± 0.09
Total Expected	12.50 ± 0.28 ± 0.46 ± 0.68
Observed	**16**

ZZ → 4 leptons

CDF & D0 use different theory
Normalizations: 2.1pb vs 1.6pb



2.51+-0.16	1.71+-0.11	ZZ expected
0.029+-0.021	0.17+-0.04	Bkg expected
1 (4μ)	1 (eeμμ)	Yield observed
1.5fb-1	1fb-1	Lumi
4.0pb	4.3pb	95% CL limit

$ZZ \rightarrow ll\nu\nu$ @

- Same selection and analysis as H->WW

  (See Ben Kilminster's talk on Wednesday)

  – Except tighter MET cut to suppress DY

  – Use Matrix Element Method to define event probability.

  – Use event probabilities to define Likelihood Ratio (LR):

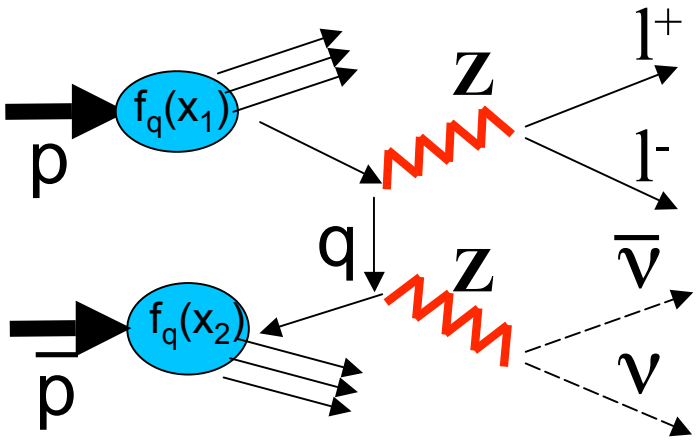
$$LR = \frac{P_{zz}}{P_{zz} + P_{ww}}$$

  – Fit LR templates for ZZ cross section.

Matrix Element Method

Event Probability Density

$$P(x_{obs}) = \frac{1}{<\sigma>} \int \frac{d\sigma_{th}(y)}{dy} \epsilon(y) G(x_{obs}, y) dy$$

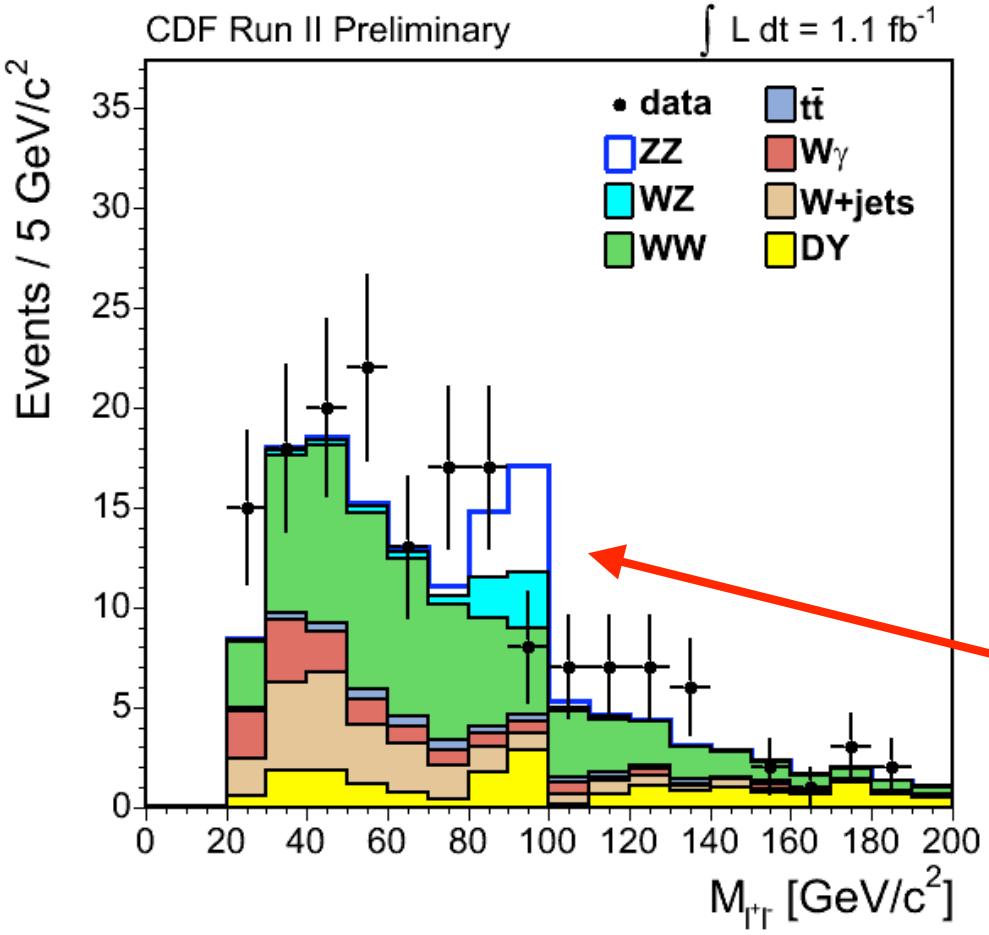


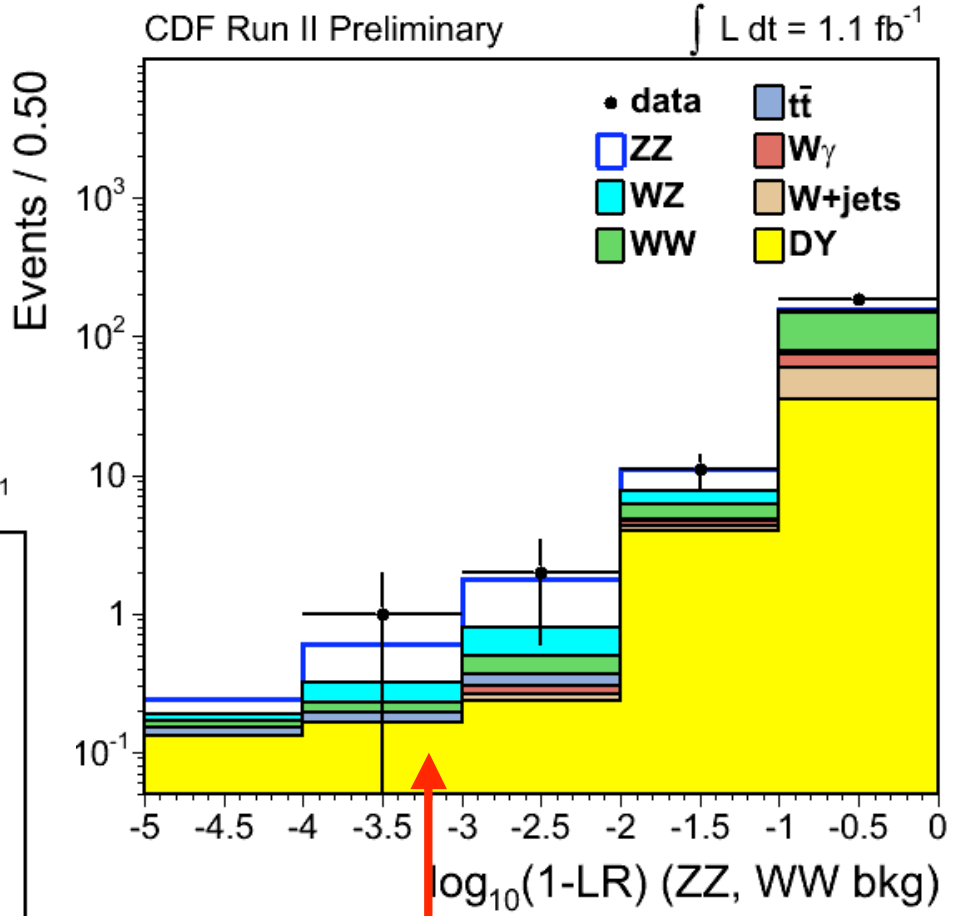
Measure MET & leptons
Integrate over ν's and partons, convoluting with eff. & resolution.

x_{obs}: $\vec{L}^+$, $\vec{L}^-$, $\not{E}_{Tx}$, $\not{E}_{Ty}$
y : true value
σ_{th} : MCFM LO Parton Level Xsec

ε : efficiency
G : Resolution
<σ>: Normalization

$ZZ \rightarrow ll\nu\nu$





3 golden events

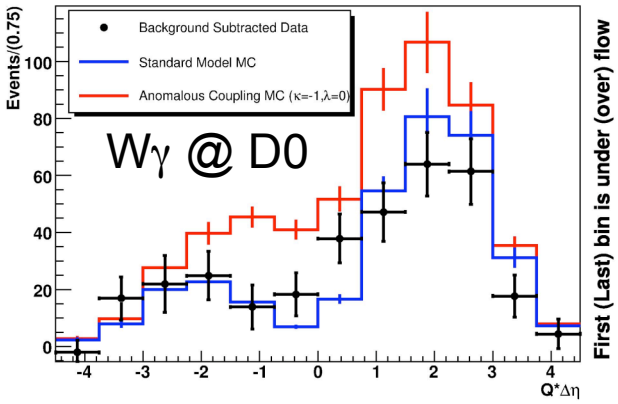
Overall less yield in Z peak than expected

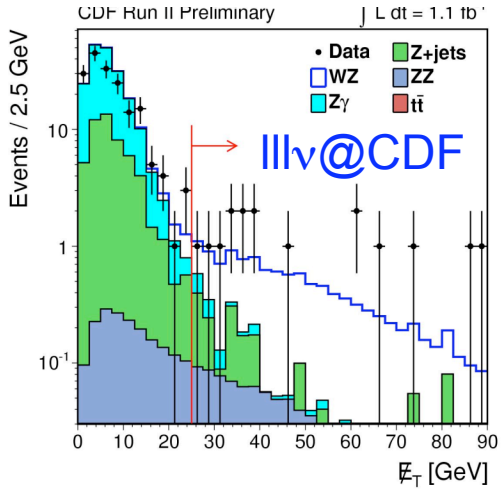
"Evidence for" ZZ production

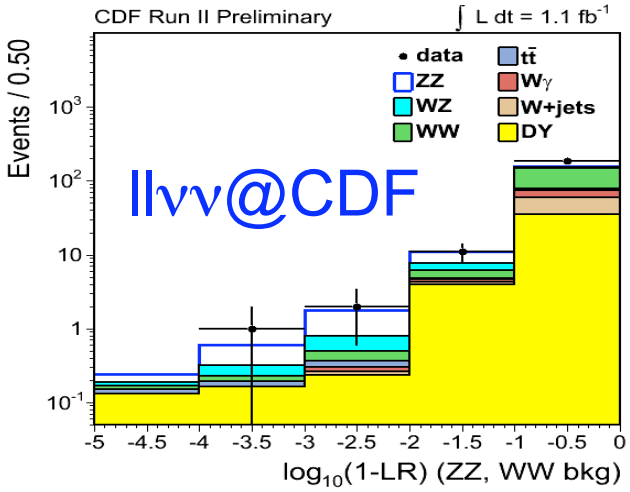
1.71+-0.11 signal + 0.17+-0.04 bkg expected.
1 eeμμ event observed.

		$ll\nu\nu$	4 lepton	Combined
prob 2σ	Expected Significance	0.50	0.92	0.88
prob 3σ		0.27	0.71	0.77
prob 5σ		0.05	0.24	0.51
Observed Signifi cance		1.9	2.2	**3.0σ**
95% CL Limit (pb)		5.2	4.0	(3.1)

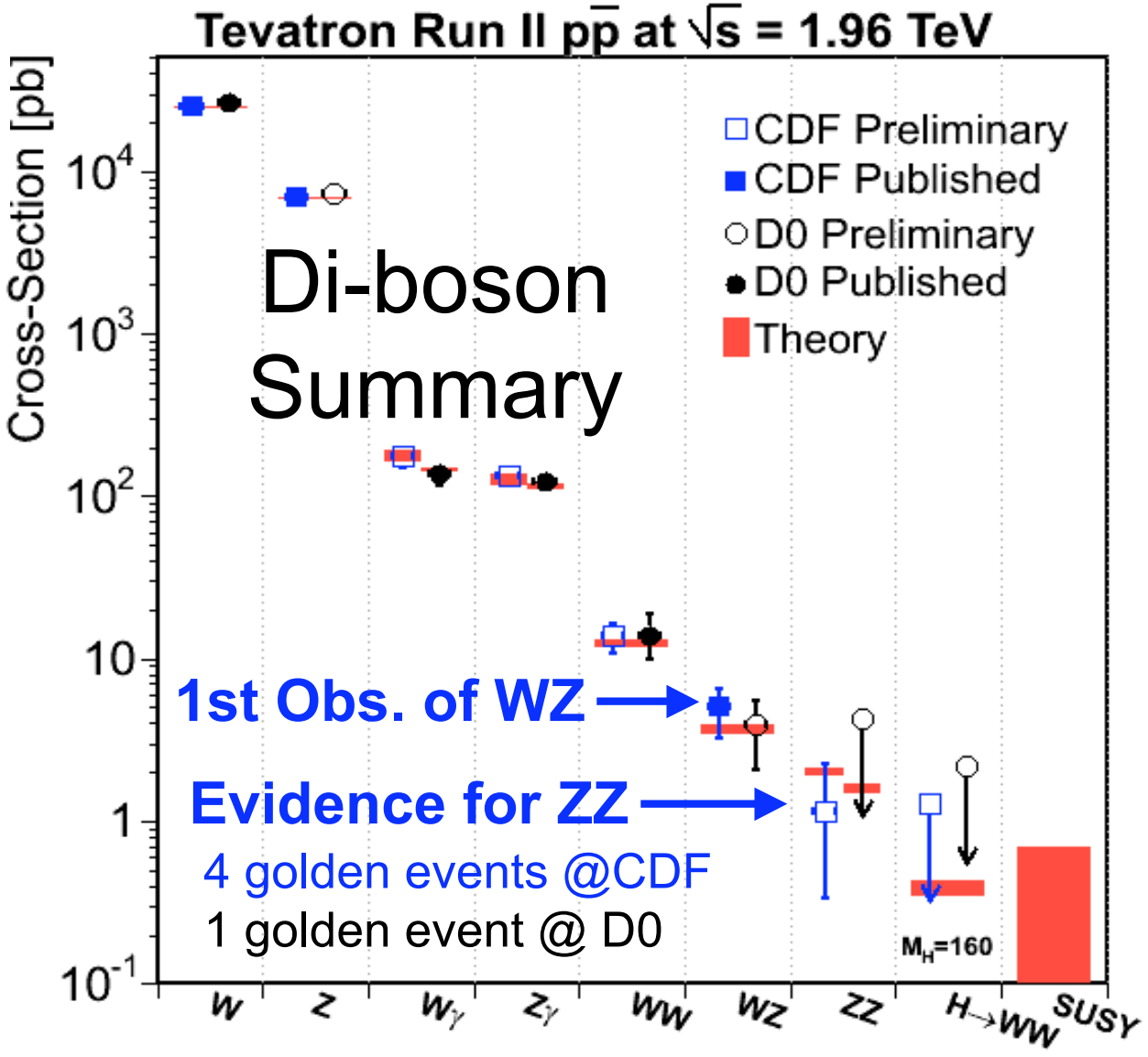
CDF measured cross section: 1.14+- 0.89 pb
Theoretical Expectation: 2.1pb



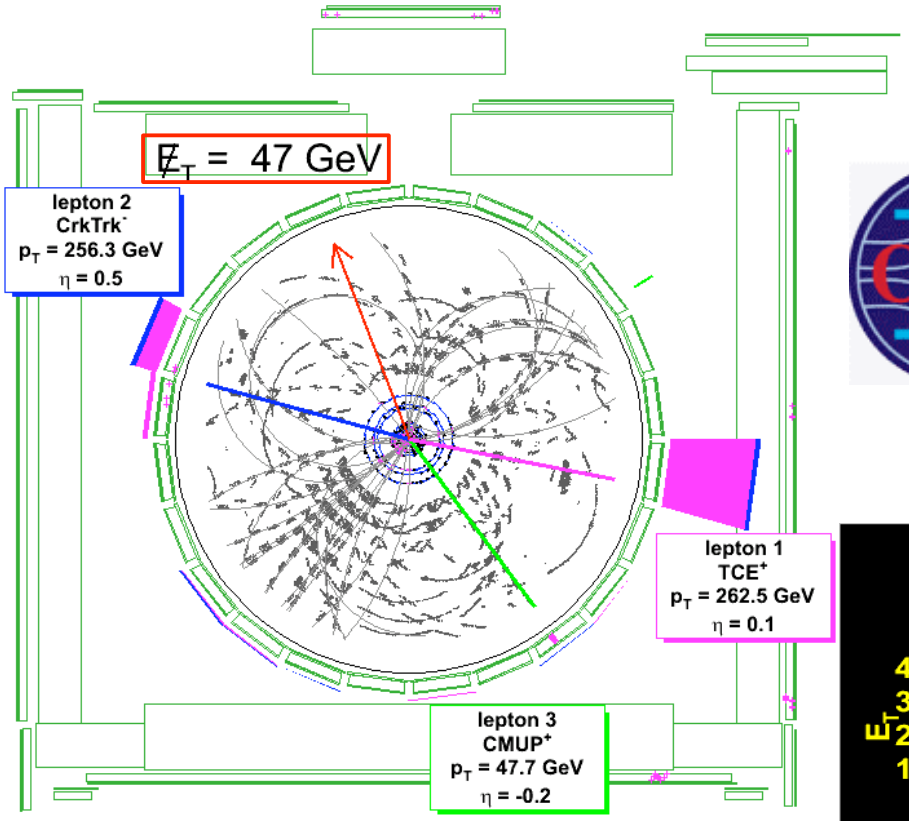


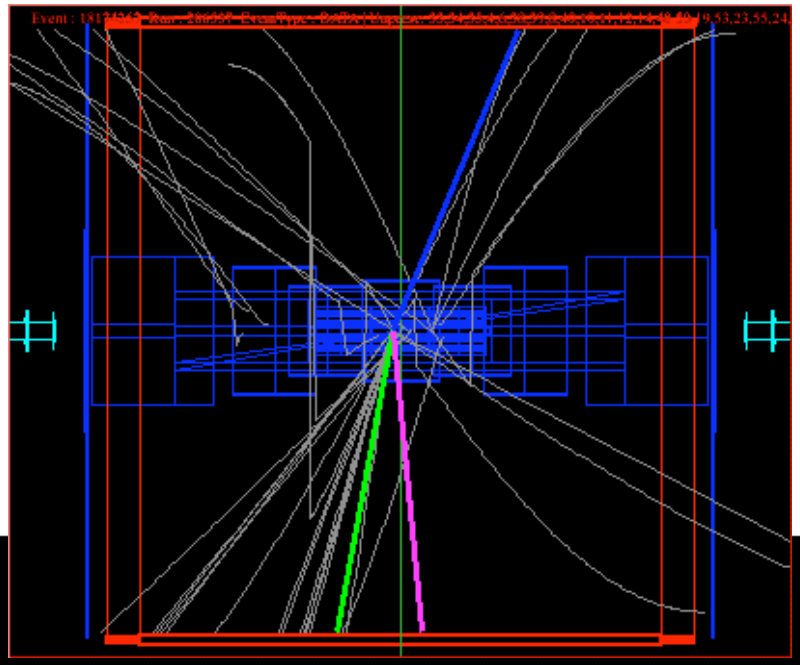


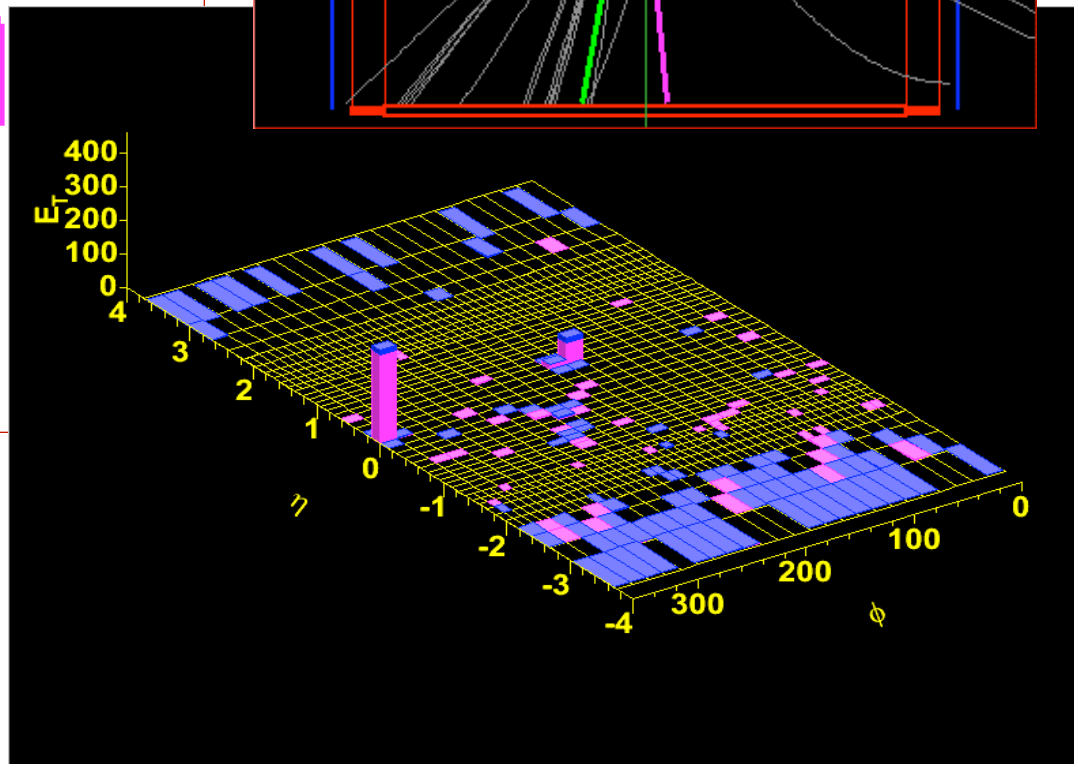
← Rad. Amp. Zero in Wγ @ D0



WZ bkg event to ponder over Grappa







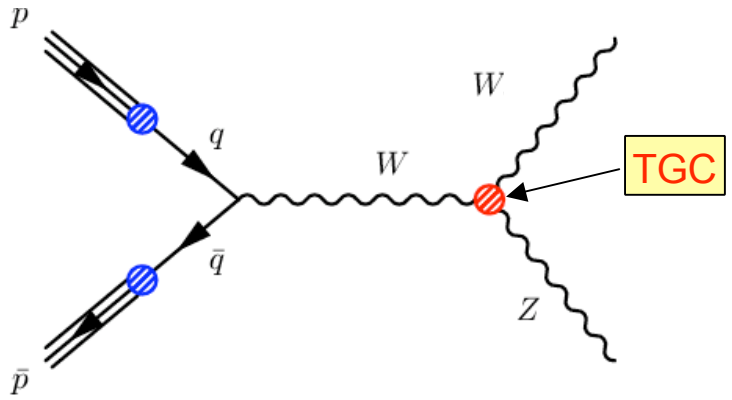
Run=206537 Event=18174367

m_{12}=526.54 GeV $|\not\!\!E_T|$=46.9 GeV
m_{13}=88.37 GeV $\Delta\phi(\not\!\!E_T, \text{lepton, jet})$=0.9
m_{23}=223.02 GeV

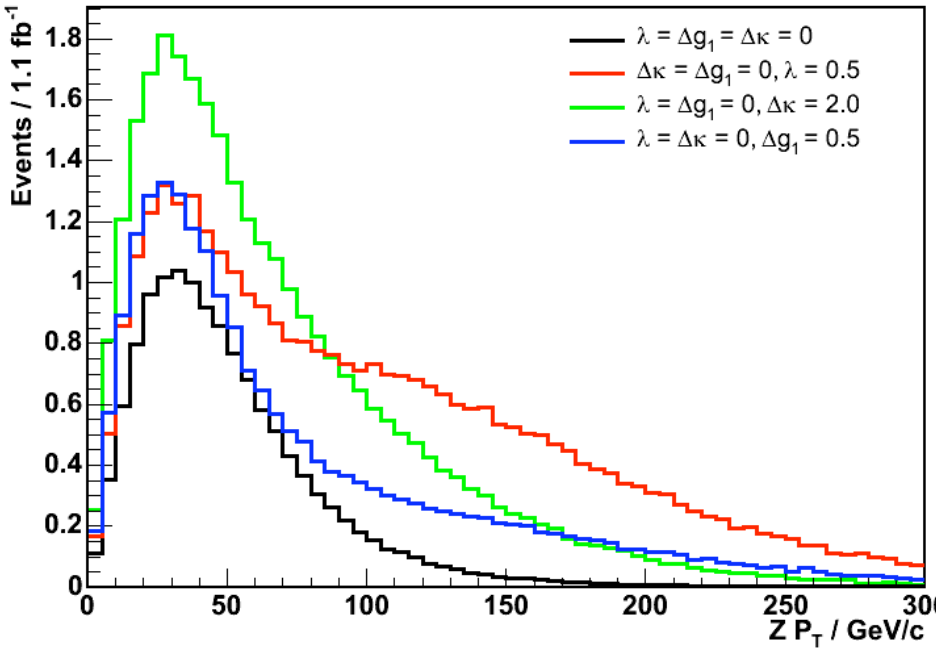
Type	p_t	η	ϕ
Central e	262.5	0.1	-0.2
Track e/μ	256.3	0.5	2.9
Central μ	47.7	-0.2	-0.9

Outlook: Limits on Anomalous TGCs..

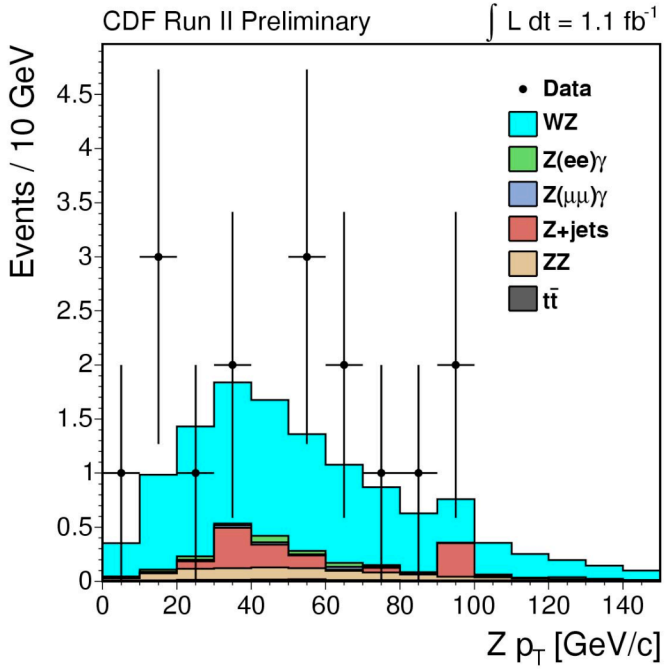
Place stringent model-independent limits on anomalous WWZ triple gauge coupling (TGC)



Generator Level MC



CDF data & SM expectation



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